Water and Fertilizer Management for Garlic: Productivity, Nutrient and Water Use Efficiency, and Postharvest Quality

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Objectives
This three-year experiment was established at the UC Westside Research and Extension Center in the fall of 1996 for 1997 harvest, in the fall of 1997 for 1998 harvest and in the fall of 1998 for summer 1999 harvest. An additional year of work (1999-2000) has been started because of the poor growing conditions in the 1997-1998 year. Therefore the final results will not be completed until Dec 2000. The objectives of the research are to:

1) Relate fertilizer and irrigation management to yield, and efficiency of water to fertilizer use
2) Determine leaf tissue concentrations of nitrogen in relation to fertilizer & irrigation practices
3) Relate leaf tissue analyses to quality at harvest.

4) Relate the postharvest quality of intact and fresh-peeled garlic to different fertilization and irrigation practices.

Summary
This report covers yield/quality results of harvested garlic from year 3 of the three year project at UC Westside Research and Extension Center, Five Points, CA. Two field trials were conducted in 1999. The irrigation trial was conducted with 2 levels of water application based on % evapotranspiration and 2 water cutoff dates. Five nitrogen fertilization were applied in combination with the 4 irrigation regimes. Quality data was taken for all the irrigation regimes and 3 of the 5 fertilization treatments. The PK trial was a repeat of the 1998 trial.

Pungency was estimated by 3 different methods. The first is the measurement of pyruvate, a byproduct of alliinase enzyme activity. The second is a measure of thiosulfinate concentration, with thiosulfinates being the principle product produce by alliinase activity. And the third was the determination of alliin, substrate for alliinase activity. In this report data for pyruvate and thiosulfinate assays are presented.

Average weight per bulb was notably reduced with the lowest N rate, but not affected by irrigation regime. The % dry weight was consistently reduced at the highest N rate across the 4 irrigation treatments. The % solids followed a more variable pattern but was lowest with the lowest amount of irrigation. Average % soluble solids were much higher than values for 1998 trials.
Pyruvate concentrations decreased with increasing N rate, a trend observed in 1998 data as well. Thiosulfinate concentrations were highest with the highest N rate for the irrigation regimes of lowest applied water. Higher N cloves were less firm than others and there were minor differences in color of the cloves.

There were no significant differences in yield or bulb weight among the PK treatments, however low P reduced weight/bulb. There were no significant differences among the PK treatments in % dry weight, and only small differences in % soluble solids. No application of P and K resulted in the lowest pungency levels.

Results and Discussion:
Summary of 1999 Garlic Research
Establishment and management of field plots
Water management regimes.
Proposed irrigation treatments for 1990 consisted of water applications equal to 110% (T1, T2), and 130% (T3, T4) of the potential evapotranspiration. Irrigation cutoff dates are shown in **Table 1**. The N fertilization rates applied in 1999 are summarized in **Table 2**. The plot plan for 1998-1999 is attached as **APPENDIX A.**

Table 1. Summary of irrigation treatments applied 1998-1999.

Irrigation Treatment	Applied Water % Evapotrans.	**Irrigation cut-off date 1999**
T1	110	10 May
T2	110	24 May

T3	130	10 May
T4	130	24 May

Table 2. Summary of N fertilization treatments applied 1998-99.

N Fertilization Treatment	Total # N applied	Preplant 11-62-0	Preplant Urea	Sidedress Urea[1]	First Water run Nitrogen[2]	Second Water Run Nitrogen[3]	Third Water Run Nitrogen
F1	100	28	41	31	0	0	0
F2	175	28	41	46	30	30	0
F3	250	28	41	121	30	30	0
F4	300	28	41	151	40	40	0
F5	400	28	41	251	40	40	0

[1]Sidedress applied between Jan 28-Feb4.
[2]First water run nitrogen applied April 1
[3]Second water run nitrogen applied April 15

Fertilizer regimes

Table 3 describes the PKfertilization trial treatments actually applied in fall 1998. All plots received same N fertilization.   PK treatments for 1999 were the same as thoses applied for 1998 crop.

Table 3. Phosphorus and Potassium fertilization treatments applied in fall 1997.

PK Treatment No.	P	Preplant K	Side Dress K
1	0	0	0
2	0	100	0
3	0	0	100
4	0	100	100
5	60	0	0
6	60	100	0
7	60	0	100
8	60	100	100
9	120	0	0
10	120	100	0
11	120	0	100
12	120	100	100

Soil and Tissue Analyses

Tissue nutrient analyses
No leaf tissue sample data is available yet for 1999

Soil nitrogen sampling and analyses.
No soil nitrogen analyses are available yet for 1999.

Quality Evaluations at Harvest

Field preparation and harvest operations.
The last irrigation was June 4. Harvest for yield and quality was accomplished in late June. Bulbs were cured, undercut, and mechanically dug. Yield data for 5-ft manually harvested parts of the 20-ft plots was analyzed for the Irrigation-N fertilization trial and the PK trial.
For the quality/postharvest evaluations, all garlic was manually dug late June (June 22 and 29). After digging, bulbs were placed in mesh bags, transported to UC Davis and cured for 3 weeks in under a field shed with good air ventilation.

Yield, grade, plant maturity characteristics. Observations were made during the last stages of development. Bulbs from each plot were graded into 4 size categories. Yields were determined on 3 subplots within each treatment plot. Data from mechanically harvested garlic was taken by Rogers Foods and is not yet available.

Laboratory analyses after harvest. Garlic were evaluated for soluble solids contents and % dry weight. Selected samples were also analyzed for pungency by the pyruvate assay and by a more specific thiosulfinate assay. Results for both assays are presented on a fresh and dry weight basis. Peeled garlic cloves were also analyzed for color and texture.

1999 Fertilization-Irrigation Trial

Averaging across nitrogen fertilization treatments, bulb weight per 5-ft subplots was less with higher rate of irrigation treatments (**Table 4)**. No significant differences were found in weight per bulb. Averaging across irrigation treatments, total bulb weight per 5-ft subplot was significantly less with 100# N total (**Table 5**). Average weight per bulb was also notably reduced with the lowest N rate. **Table 6** shows yield data for each irrigation-N fertilization plot. The lowest N rate reduced total bulb weight and weight per bulb under all 4 irrigation regimes.

The % dry weight was consistently reduced at the highest N rate across the 4 irrigation treatments (**Table 7**). The % solids followed a similar pattern for T1 and T2 irrigation treatments, but not for T3 and T4. Average % soluble solids were much higher than values for 1998 trials.

Contrary to 1998 results, trends in pyruvate and thiosulfinate concentrations were not consistent (**Table 7**). Pyruvate concentrations decreased with increasing N rate, a trend observed in 1998 data as well. Thiosulfinate concentrations which were highest with the highest N rate for T1 and T2 irrigation regimes. For the T3 and T4 regimes, there were no differences in thiosulfinate concentrations among the nitrogen fertilization treatments.

Measurement of garlic clove texture with a computerized texture analyzer (force of penetration with a 2 mm probe to a depth of 5 mm) demonstrated that increasing N rate resulted in decreased firmness (**Table 8**). This trend was consistent across the 4 irrigation regimes.

Objective color measurements showed that the cloves from all fertilization treatments for T2 and T4 irrigation regime were the lightest (highest L* values) (**Table 8**). These regimes had the later water cutoff dates. Cloves from T1 and T3 irrigation regimes had the lower chroma values (chroma=color intensity)

Table 4. Yield data for irrigation treatments applied in 1999. Data are averages of 6 field replications. Data are averaged across fertilization treatments.

Treatment	Applied Water, % Evapotrans.	**Irrigation cut-off date**	Bulb Count*	Bulb Weight, kg*	Piece weight, g/bulb
T1	110	10 May	117.3	6.75	58.0
T2	110	24 May	113.0	6.36	61.1
T3	130	10 May	104.8	5.92	57.0
T4	130	24 May	111.4	6.15	55.3
LSD.05			ns	0.53	ns

* Bulb count and weights are based on 5-ft subplots.

Table 5. Yield data for Nitrogen fertilizer treatments applied in 1999. All plots received 70 lb N/acre pre-plant. Data are averages of 6 field replications, across irrigation treatments.

Treatment	Total # N	Bulb Count*	Bulb Weight* kg	Piece weight g/bulb
F1	100	111.1	5.45	49.2
F3	250	109.8	6.58	60.5
F5	400	114.0	6.85	63.9
LSD.05		ns	0.53	7.6

* Bulb count and weights are based on 5-ft subplots.

Table 6. Yield data for Irrigation-N fertilization treatments applied in 1999. All plots received 70 lb N/acre pre-plant. Data are averages of 6 field replications.

Irrigation Treatment*	N Fertilization Treatment	Bulb Count**	Bulb Weight, kg**	Piece weight, g/bulb
T1	1	122.2	6.0	49.1
	3	117.2	7.2	61.1
	5	112.5	7.1	63.8

T2	1	107.8	5.6	52.2
	3	109.3	6.3	58.5
	5	121.8	7.1	72.5
T3	1	110.5	5.1	45.9
	3	96.7	6.2	64.1
	5	107.3	6.6	61.1
T4	1	103.8	5.1	49.5
	3	116.0	6.7	58.3
	5	114.5	6.6	58.2
LSD.05		ns	0.5	7.6

* See table 4 and 6 for treatments.

* * Bulb count and weights are based on 5-ft subplots.

Table 7. Composition of PEELED GARLIC CLOVES from 1999 Irrigation-N fertilization trial. Analyses were done after field and laboratory curing (about 4 weeks). Data are averages from 30 outer cloves from a minimum of 10 bulbs per evaluation. See **Table 1** and **2** for fertilization treatments.

Irrigation Treatment	N fertilization treatment	Dry Weight (%)	Soluble Solids (%)	Pyruvate µm/g FW	Pyruvate µm/g DW	Thio-sulfinate µm/g FW	Thio-sulfinate µm/g DW
T1	1	41.1	43.2	17.6	42.9	24.5	59.5
	3	40.3	43.5	16.3	40.3	24.3	60.4
	5	39.0	42.3	13.7	35.1	26.0	66.6
T2	1	41.1	43.7	15.4	37.4	23.1	56.4
	3	39.6	43.0	14.2	35.9	21.8	55.0
	5	39.5	42.1	10.9	27.6	25.2	64.0
T3	1	41.0	42.3	15.7	38.2	24.6	59.9
	3	40.3	43.6	13.6	33.6	23.6	58.7
	5	39.1	42.6	10.7	27.3	23.8	60.7
T4	1	40.6	43.3	17.9	44.1	27.8	68.5
	3	40.3	43.3	11.7	29.1	28.0	69.5
	5	39.7	43.0	11.0	27.8	28.8	72.5
LSD.05		0.8	0.4	1.2	2.9	2.4	6.1

[1] Pungency estimated as µmole pyruvate/g fresh or dry weight or as thiosulfinate in µmole pyruvate/g fresh or dry weight; data are averages of 3 composite samples per treatment.

Table 8. Color and firmness of PEELED GARLIC CLOVES from 1999 Irrigation-N

fertilization trial. Analyses were done after field and laboratory curing (about 4 weeks). Data are averages from 30 outer cloves from a minimum of 10 bulbs per evaluation. See **Table 1 and 2** for fertilization treatments.

Irrigation	N fertilization	Firmness	Objective color values				
Treatment	treatment	Newton	L*	a*	b*	Chroma	hue
T1	1	16.6	78.1	-2.87	12.1	12.5	103.3
	3	15.7	77.4	-2.76	12.3	12.6	102.7
	5	15.2	77.0	-2.65	12.2	12.5	102.2
T2	1	17.3	79.1	-2.96	11.9	12.3	103.9
	3	15.8	78.9	-3.01	13.1	13.4	103.0
	5	15.5	78.3	-2.87	13.1	13.4	102.4
T3	1	16.5	77.5	-2.84	11.9	12.2	103.4
	3	16.3	77.4	-2.85	12.2	12.5	103.2
	5	15.2	77.4	-2.67	11.8	12.1	102.7
T4	1	16.6	79.6	-3.17	12.6	13.0	104.1
	3	15.8	79.2	-2.97	12.8	13.1	103.1
	5	15.3	79.3	-2.87	12.1	12.5	103.3
LSD.05		0.7	0.9	0.2	0.7	0.7	0.8

[1] Firmness determined as newtons with a 3 mm probe to a 5 mm depth; data based on 90 cloves per treatment.
[2] Chroma calculated from a* and b* color values; chroma = $((a^*)^2+(b^*)^2)^{1/2}$. Hue calculated as arctan of b*/a*. L indicates lightness with 0=black and 100=white.

1999 PK Fertilization Trial

There were no significant differences in yield or bulb weight among the PK treatments (**Table 9**). However low P notably affected g/bulb (Table 9), whereas K application did not.

There were no significant differences among the PK treatments in % dry weight (**Table 10**). The % soluble solids was slightly lower at the higher fertility level (Table 10). Although there were significant differences in pyruvate and thiosulfinate concentrations, there was not a consistent trend with regards to P and K fertilization (Table 10). No PK application resulted in the both the lowest pyruvate and lowest thiosulfinate levels.

Firmness was not affected by PK nutrition (**Table 11**). The L* color values (lightness) were higher in the PK trial than in the Irrigation-N fertization trial (Table 8). Other color values differed little among the PK treatments.

Table 9. Yield data for **PK** fertilizer treatments applied in 1999. All plots received the same nitrogen. Data are averages of 6 field replications.

Treatment	Total # P	Total # K	Bulb Count*	Bulb Weight* kg	Piece weight g/bulb
1	0	0	136.3	6.11	44.9
4	0	100	133.3	6.04	45.4
6	60	100	125.5	6.29	50.1
9	120	0	118.3	6.71	57.1
12	120	100	114.3	6.24	55.3
LSD.05			ns	ns	5.7

* Bulb count and weights are based on 5-ft subplots.

Table 10. Composition and other quality aspects of PEELED GARLIC CLOVES from 1999 PK fertilization trial. Analyses were done after field and laboratory curing (about 4 weeks). Data are averages from 30 outer cloves from a minimum of 10 bulbs per evaluation. See **Table 3** for fertilization treatments.

PK Treatment	Dry Weight (%)	Soluble Solids (%)	Pyruvate µm/g FW	Pyruvate µm/g DW	Thiosulfinate µm/g FW	Thiosulfinate µm/g DW
1	40.2	42.8	13.9	34.5	23.2	57.8
4	39.6	42.8	17.5	44.2	24.3	61.4
6	39.4	42.5	16.1	40.9	24.8	62.9
9	39.3	42.2	18.0	45.9	24.5	62.3
12	39.6	42.3	15.2	38.3	28.8	72.7
LSD.05	ns	0.4	1.1	2.8	3.8	9.6

[1] Pungency estimated as µmole pyruvate/g fresh or dry weight or as thiosulfinate in µmole pyruvate/g fresh or dry weight; data are averages of 3 composite samples per treatment.

Table 11. Color and firmness of PEELED GARLIC CLOVES from 1999 PK fertilization trial. Analyses were done after field and laboratory curing (about 4 weeks). Data are averages from 30 outer cloves from a minimum of 10 bulbs per evaluation. See **Table 3** for fertilization treatments.

PK	Firmness	Objective color values				
Treatment	Newton	L*	a*	b*	Chroma	hue
1	15.2	79.9	-2.91	12.4	12.8	103.2
4	15.3	80.5	-2.80	12.0	12.3	103.1
6	15.4	80.4	-2.83	12.4	12.7	102.9
9	15.4	80.1	-2.90	12.7	13.1	102.9
12	15.4	80.5	-2.87	12.6	12.9	102.9

LSD.05	ns	0.4	0.10	0.4	0.4	ns

[1] Firmness determined as newtons with a 3 mm probe to a 5 mm depth; data based on 90 cloves per treatment.
[2] Chroma calculated from a* and b* color values; chroma = $((a^*)^2+(b^*)^2)^{1/2}$. Hue calculated as arctan of b*/a*. L indicates lightness with 0=black and 100=white.

Postharvest Storage and Processing Evaluations

No information to report yet for 1999.

Outreach Activities

Extension and industry meetings. R. Voss provided a synopsis of the project to the Onion and Garlic Workgroup meeting held as part of the Vegetable Crops Continuing Conference at UC Davis (Dec 3, 1999). This Workgroup consists of UC extension advisors and specialists and vegetable researchers. A 3 page summary of the project (1998 data) was included in the Proceedings of the 1999 FREP Conference held in Modesto Nov 30, 1999.

APPENDIX B. Summary of standard scoring systems and other measurements for determination of garlic quality.

Quality Parameter	Description of Measurement
WHOLE BULBS	Data are averages from 30 bulbs per treatment
Visual quality	9 to 1 scale, where 9=excellent, 7=good, 5=fair, 3=poor; 6 is limit of salability.
Firmness of whole bulb	based on hand compression using 5 to 1 scale, where 5=firm, 3=moderately firm, and 1=soft.
Decay	1 to 5 scale, where 1=none, 3=moderate, 5= severe
Rooting	1 to 5 scale, where 1=none, 3=moderate, 5= severe
Sprouting on whole bulbs	scored as a fraction of the clove length without sectioning. A score of one indicates sprout not visible in the intact clove
PEELED CLOVES	Data are averages from 60 cloves per treatment
Visual quality	9 to 1 scale, where 9=excellent, 7=good, 5=fair, 3=poor. A score of 6 is limit of salability.
Decay	1 to 5 scale, where 1=none, 3=moderate, 5= severe
Sprouting on peeled cloves	Cloves were sectioned longitudinally and the length of the sprout was estimated as a fraction of full clove length; a score of 1.00 indicates that sprout equals clove length.
Root development	Maximum root development measured in mm length.
Pungency as pyruvate	estimated as µmole pyruvate/g dry weight; data is average of 3 or 6 composite samples per treatment.
Pungency as thiosulfinate	For some samples, a colorimetric analysis, more specific for thiosulfinate concentration, was used. Data are reported as
Pungency by alliin assay	Alliin, precursor to thiosulfinates in garlic was determined by HPLC from freeze-dried samples; data are expressed as mg/g dry weight
Firmness	estimated as newtons force to penetrate with a 3 mm probe; data based on 30-90 cloves per treatment.
Color values	L is indication of lightness, with 0=black and 100=white. Chroma calculated from a* and b* color values; chroma = $((a^*)^2+(b^*)^2)^{1/2}$. Hue calculated as arctan of b*/a*.
% soluble solids	Determined by pressing fresh samples in a press and reading soluble solids directly on a refractometer.
% Dry weight	Fresh samples are dried at 70°C to determine % dry weight
Fructan	Fructan, the major carbohydrate of garlic, was determined by HPLC from water extracts of freeze-dried samples; data are expressed as mg/g dry weight

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Water and Fertilizer Management for Garlic

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Summary

Garlic is a cool season vegetable crop with a long growing season – approximately October to July. The potential nutrient and water needs are, therefore, high. Compared to onion, garlic has a more extensive root system that can access and uptake water and nutrients to a depth of at least 3 ½ feet, thus garlic is more efficient than onions. Research trials conducted during the 1980's and 1990's were inconsistent in optimum fertilization rates and irrigation timing and amounts. These experiments have, however, increased the knowledge about water and nutrient management of garlic in California.

Irrigation Timing and Amounts. Highest yields are probable with soil moisture depletion of as little as 25-30% depletion, certainly lower than 50%. Starting the season with the soil profile full of moisture is essential to reaching optimum production. Subsequent irrigation with as little as 12-15 acre inches of water is frequently sufficient. Irrigation frequency, with furrow or sprinkler, of 7-10 days on soils with approximately 2 – 2 ¼ inches of available water per foot of soil provided highest yields. Drip irrigation of 0.4 – 0.8 inches per application provided equal yields.

Evapotranspiration can also be used as a guideline for irrigation timing and amounts. In 1998-1999 a sprinkler line source experiment was conducted to determine the crop

coefficient for garlic. Irrigating at **APPENDIX C**
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either 110% or 130% of ET gave approximately equal yields. Garlic extracted water deeper than the 42 inches, the maximum depth depth of soil moisture measurements in this experiment. Results from the first year of this line source experiment were as follows:

1. Garlic yield was independent of applied water for conditions where a deep fine textured soil is, initially, at field capacity. Applied water varied from about 4 inches to 13 inches, yet no yield response was found.

2. Garlic is capable of extracting considerable water in a fine textured deep soil at depths deeper than 3.5 feet as shown by plots of the neutron probe data with time. The sum of the seasonal change in soil moisture content and applied water was nearly equal with distance from the sprinkler line until near the edge of the wetted area of the sprinkler, where much extraction appeared to occur at the deep depths.

3. Little change in crop canopy occurred with distance from the sprinkler line except at the last sample site, 38 feet from the sprinkler.

Irrigation cutoff date, or date of last irrigation, has a great influence on garlic yield. Yields increase with later cutoff dates. This effect is lower if higher levels of irrigation are used during the season, providing a full soil profile for the crop to gradually deplete. Quality can be reduced, however, with late irrigation. The most serious is the potential for stem/root plate rot. Plant population at harvest can be significantly decreased with increasingly later irrigation cutoff dates. Storageability is also decreased.

<u>Fertilization.</u> Response to fertilizer depends on soil type, past cropping, and the yield potential of the variety or strain planted. “Virus-free” garlic, for example, responds to higher rates of nitrogen than non-virus free seed lots, because the yield potential is significantly higher and maturity is generally later.

Garlic rarely responds to phosphorus, potassium or zinc when grown on the heavy deep soils of the West Side of the San Joaquin Valley. Similar results were obtained in Kern County and Salinas Valley experiments.

Optimum nitrogen rates in the numerous experiments conducted by the University of California over the past 20 years have varied from 100 to 400 lbs. N per acre. Nitrogen, as well as moisture, availability early in the growing season is essential for optimal growth. Late applications of nitrogen may be deleterious to both yield and quality. Growth is slow during the first four months after planting. Thus, the greatest nitrogen needs are when growth begins in late winter and early.

Response to phosphorus fertilization has been infrequent and poorly correlated to soil test levels. When response was measured, 50 lbs per acre was adequate for maximum yield. Response to potassium fertilizer has been rare. Zinc response was measured at the rate of 20 lbs/acre when soil test levels were approximately 0.5 ppm. No response was measured at soil levels of 2.0 ppm.

Leaf nitrate and total nitrogen are directly related to nitrogen fertilizer but do not appear to be affected by irrigation. Total N is a better indicator of adequacy, with levels of 4-5% at early season (pre-bulbing), 3-4% at mid-season (bulbing) to pre-cutoff date, and 2-3% at late season (near irrigation cutoff) correlating well with yield response.

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Garlic Quality. Fertilizer and water management influences harvest quality and postharvest quality. Both nitrogen and irrigation affect soluble solids, or dry matter content. In general, dry matter is reduced as nitrogen fertilizer rates increase, particularly at rates higher than optimum for yield. However, in some cases dry matter was lower at nitrogen levels sub-optimum for yield. Water stress also results in lower dry matter content. Cutoff date is again important; dry matter content increases during the season. Thus, if irrigation cutoff is too early, dry matter can be reduced. The risk of late cutoff date was discussed above.

Preliminary results indicate that cloves in storage sprouted earlier if they had been subjected to higher soil moisture regimes. Nitrogen fertilization did not affect sprouting. Pungency increased with length of time in storage for all field and storage treatments. Yellowing of cloves also increased with time. Storage conditions have a much greater influence on garlic bulb and clove quality than does the fertility and water management during production. Phosphorus and potassium fertilizer, while not having any effect on yield, may positively influence dry matter percent, percent soluble solids, firmness and white color at harvest. Phosphorus, without potassium, however, resulted in the poorest clove color and the highest pungency.

A sprinkler line source experiment with nitrogen rates is again being conducted this year at the UC Westside Research and Extension Center to further study the objectives of determining the relationships of water management, fertilizer management, garlic productivity and garlic quality.

Appreciation is expressed to Rogers Food, CDFA Fertilizer Research and Education Program, and American Dehydrated Onion and Garlic Association for financial and research support of these studies.

OBJECTIVES

1. Relate fertilizer and irrigation management of garlic to yield and to the efficiency of water and fertilizer use.
2. Determine garlic leaf tissue concentrations of nitrogen in relation to fertilizer and irrigation practices and relate to crop quality at harvest and postharvest.
3. Develop crop coefficients relating garlic evapotranspiration to CIMIS reference crop evapotranspiration.
4. Relate postharvest quality of intact and fresh peeled garlic to different fertilization and irrigation practices.
5. Determine if slow release nitrogen fertilizers are equal or superior to more soluble nitrogen forms.

EXPERIMENTS

1. Nitrogen rate experiments, ranging from 0 to 500 lbs./A.
2. Nitrogen timing experiments – pre-plant, side-dress, water-run.
3. Nitrogen source experiments.
4. Phosphorus rate experiments.
5. Potassium rate and timing experiments.
6. Irrigation rate experiments based on soil moisture depletion.
7. Irrigation rate experiments based on evapotranspiration.
8. Irrigation timing experiments based on calendar.
9. Irrigation timing experiments based on cutoff dates.
10. Irrigation method experiments – furrow, sprinkler, drip.

11. Sprinkler line source experiments.
12. Postharvest controlled atmosphere storage treatments.

MEASUREMENTS

1. Yield (tons per acre).
2. Bulb size (weight)
3. Soluble Solids of cloves.
4. Leaf Total N and Nitrate N.
5. Leaf Total P and Total K.
6. Soil moisture content with neutron moisture meter throughout the season to depth of 4 feet.
7. Soil moisture content with Enviroscan system throughout the season to depth of 4 feet.
8. Canopy coverage with digital near-infrared camera.
9. Depth of water applied.
10. Respiration rates of stored peeled and intact cloves.
11. Storageability – weight loss, decay, sprouting, rooting, firmness, color
12. Pungency (pyruvate, thiosulfinates, alliin)
13. Sugar and fructan content

Tables 1–4 and Figure 1 list some of the recent research results. Additional results will be presented during the Conference.

Table 1. Results of the 1997 irrigation treatments*.

Treatment	Time between irrigation	Date last irrigation	Applied Water (inches)	Bulb Count	Yield (pounds per plot)
T1	1 week	May 9	13.8	340a	29.0a
T2	1 week	May 16	17.2	342a	31.1b
T3	1.5 weeks	May 9	11.8	327a	26.1c
T4	2 weeks	May 16	14.3	334a	26.2c

* Averaged across N fertilization treatments

Table 2. N fertilizer treatments and yield data for 1997*.

Treatment	Preplant	Sidedress	Water-run**	Total lb. N/acre	Bulb Count	Yield (Pounds/plot)
F1	70	30	0	100	332a	25.6a
F2	70	90	40	200	332a	28.1b
F3	70	170	60	300	334a	29.2c
F4	70	250	80	400	344b	29.4c

* Averaged across irrigation treatments.
** Applied in four applications

APPENDIX C
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Table 3. Irrigation treatments applied in 1998. Data are averages of 6 field replications.

Treatment	Date last irrigation	Bulb Count	Bulb Weight*	Piece weight*	Total Yield*	Solids (%)
T1	May 12	615a	36.0a	2.8a	38.7a	37.2a
T2	May 19	545b	31.4b	6.6b	38.0a	36.8a
T3	May 25	447c	24.9c	8.9c	33.8b	36.1a
T4	June 4	390d	21.9c	9.5c	31.4b	36.1a

* Weights are pounds per plot
** Data averaged across fertilization treatments.

Table 4. Nitrogen fertilizer treatments applied in 1998. All plots received 70 lb N/acre pre-plant. Data are averages of 6 field replications.

Treatment	Side-dress*	Water-run*	Total*	Bulb Count	Bulb Weight*	Piece weight*	Total Yield*	Solids (%)
F1	30	0	100	565a	31.3a	2.9a	34.3b	38.1a
F2	65	40	175	527ab	30.9a	5.9b	36.8a	37.2ab
F3	140	40	250	486bc	28.4b	7.2c	35.7ab	36.6bc
F4	175	80	325	465c	26.9bc	9.1d	36.0ab	35.5c
F5	250	80	400	451c	25.1c	9.4d	34.5b	35.3c

* Pounds per plot

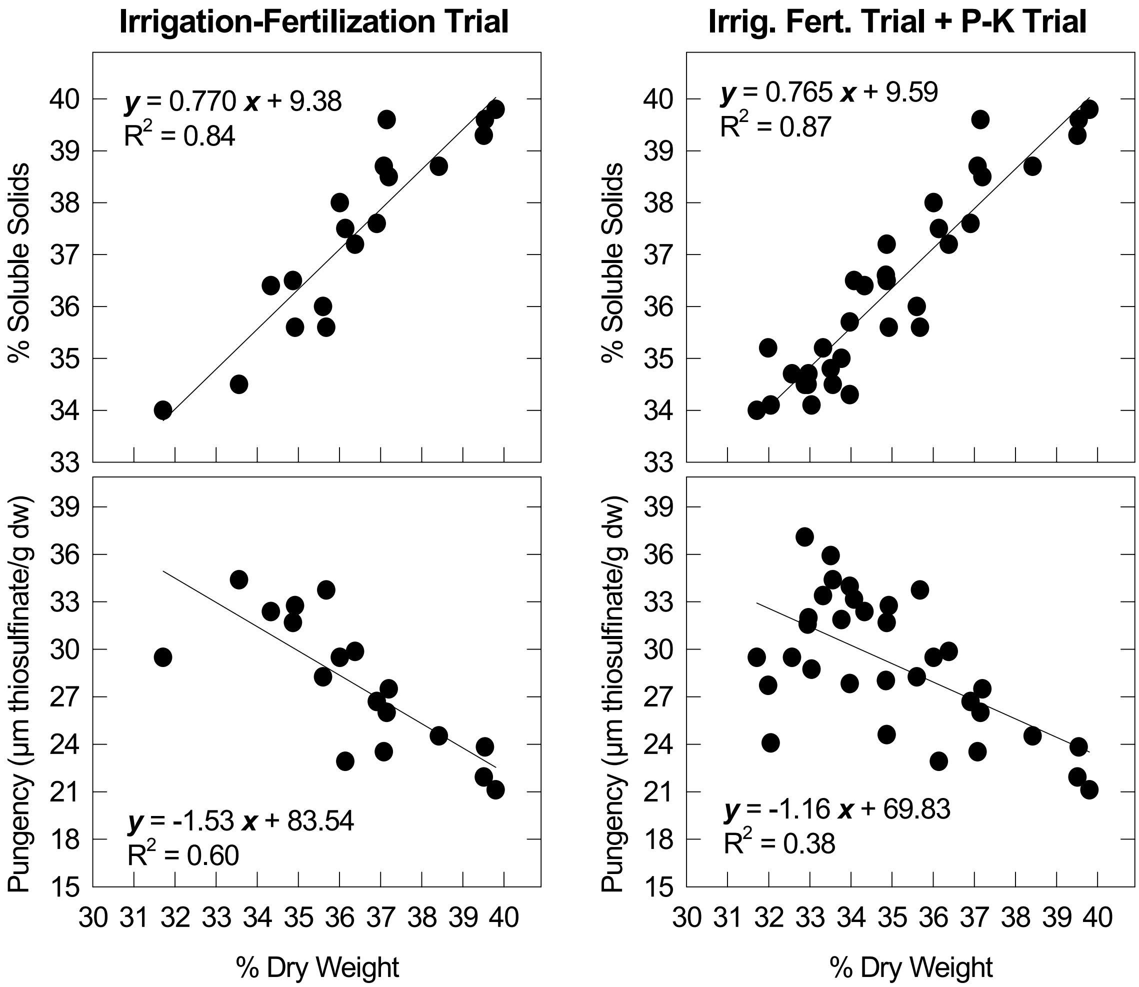

Figure 1. Relationship between soluble solids and dry weight (top panels) and pungency and dry weight (lower panels) from garlic fertilization and irrigation experiments.